Umwelt Bundesamt

EMISSION CONTROL THROUGH EXHAUST GAS CLEANING
(AND THE CLEANING OF FLUE GAS FROM THE INCINERATION OF WASTE IN PARTICULAR)

APPLICATION OBJECTIVE	- Emission abatement through the treatment and cleaning of the exhaust gases (in particular flue gases) from waste incineration processes (see also fact sheets on the different incineration technologies; "Industrial Co-combustion", "Grate combustion", "Fluidized bed incineration")

OUTLINE ON APPLICATION FRAMEWORK

PARTICULARLY APPLICABLE FOR WASTE TYPES

Glass		Light-weight packaging		Biowaste	
Paper / paperboard		Mixed household waste		Bulky waste	
Lamps		Textiles		Electrical and electronic waste	
Scrap metal		Waste wood		C&D waste	
Waste oil		Old paint & lacquer		Waste tyres	
Hazardous waste					
Branch specific waste					
Other waste material	X	Exhaust gas from the incineration of waste			

SPECIAL CHARACTERISTICS AND REQUIREMENTS OF THE APPLICATION

Pre-treatment of the input material:
The protection of the atmosphere from pollution and the precautionary principle require a treatment of gaseous and particle emissions from incineration processes as they may contain hazardous and potentially harmful substances. The treatment and cleaning of exhaust gases (especially the flue gas) is therefore a necessary, process-integrated component of waste incineration. An optimally controlled and managed incineration process can reduce the hazard risk and toxicity of the emissions considerably, making waste incineration even to one of the cleanest technologies of waste disposal in the overall.

Options for the utilisation of the generated output:
Part of the residues from exhaust gas cleaning can be recycled or further utilized (e.g. FGD gypsum)

Options for the disposal of process output and/or residues:
An essential portion of the substances washed and filtered out in the cleaning process as well as other cleaning residues require special handling due to harmful substance concentrations and hazardousness. The disposal must be undertaken at specially secured landfills for hazardous waste, a preferable option are underground storages (see fact sheet on "Landfill for hazardous waste")

Aftercare requirements:
The reaction products with problematic toxic and leachable substances (heavy metals, dioxines/furans, PAHs) as obtained in dry and semi-dry exhaust gas cleaning lead to the need for diligent aftercare which a proper post-treatment and disposal in appropriate underground storage facilities can provide (see fact sheet on "Landfill for hazardous waste"). The same applies for the evaporation residues from wet gas cleaning techiques. Aftercare measures for deposited gas cleaning residues must comply with the specific rules for the used disposal facilities.

Protective needs:
The handling of exhaust gas cleaning residues must be undertaken with the necessary precaution and protection to which belong the encapsulation and/or immobilization of the filter dust, ashes and scrubber residues.

Potential health risks:
A release of untreated flue gases pose a health risk which can be avoided if contemporary cleaning techniques and protective measures as indicated in this fact sheet are employed and properly followed. Waste incinerators using state-of-the-art cleaning technologies are nowadays considered as not threatening human health any longer.

RESTRICTIONS OR INFLUENCE OF EXTERNALITIES ON THE APPLICATION

Exhaust gas cleaning is an integrated part of any waste incineration process. Whatever conditions and restrictions influence these processes must be considered for the exhaust gas cleaning as well which is why this fact sheet should be always studied and used in combination with the information provided on the different incineration techniques (see fact sheets on "Industrial Co-combustion", "Grate combustion", "Fluidized bed incineration").

TECHNICAL DETAILS

GENERAL OVERVIEW

ABSTRACT

Exhaust gas cleaning systems serve the abatement of the hazard potential of emissions resulting from waste incineration processes and the best possible reduction of the harmful substances they contain. To the typical air polluting substances forming during the incineration processes belong:

- particulate matter, dust (PM),
- carbon monoxide (CO),
- nitrous oxides (NO_x),
- sulphur oxides (SO_x),
- halogen hydracid (HCl, HF),
- organic pollutants (e.g. PCDD/F) and
- heavy metals (e.g. Hg, Cd, As).

Effective exhaust gas cleaning systems may include dry, semi-dry and wet cleaning techniques. Wet techniques can be operated with or without the generation of waste water amounts. The cleaning effect results from the combination with flue gas desulfurization (FGD) technologies, PM control technologies, and flue gas NO_x removal and comprise several devices such as afterburners, spray quench, baghouse, electrostatic precipitators, fabric filters, wet scrubber and catalytic converters. These systems are connected to the flue gas stream and exhaust manifolds of the incineration facilities

BASIC REQUIREMENTS

Exhaust gas cleaning systems must be set up and operated with permitted technologies and have to become part of the overall plant permitting procedure. European plants are not allowed to transgress with the treated and cleaned exhaust gas the emission values as contained in the European Directive on Industrial Emissions (see fact sheet on "Technology-oriented regulations"). These values prescribe the minimum achievable standard.

Table 1: Critical emission values (limiting values) for exhaust gases from incineration processes in the EU

Parameter	Daily average in mg/Nm³ dry (at 11 Vol.-% O_2 dry)
Total dust	10
TOC	10
HCL	10
HF	1
SO_x	50
NO_x	200–400
CO	50
Hg / Sum of Cd + Tl	0.05 / 0.05
Sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V	0.5
Dioxine and Furans	0.1 ngl-TEQ/Nm³ dry (at 11 Vol.-% O_2 dry)

EXPECTED RESULTS

- a cleaned stream of exhaust gases resulting in maximum emissions as stipulated (see for example Table 1) when released over the chimney and other exhaust manifolds of the incineration facility, therefore not harming human health, other organisms and the environment
- residues, which need to be properly disposed of with respect to their load of harmful substances and toxicity, especially:
  - caldron dust, slag and ashes, filter dust
  - reaction products resulting from acid gas scrubbing
  - heavy metal-containing sludge (from gas washing/wet scrubbing)
  - loaded absorbents (e.g. activated charcoal)
  - FGD gypsum

SPECIFIC ADVANTAGES

Exhaust gas cleaning
- makes an environmentally benign incineration of waste possible
- supports environmental and climate protection efforts
- rises the general acceptance for waste incineration processes and therewith allows that these processes can be applied on larger industrial scale as an option for the save waste disposal in combination with energy recovery

SPECIFIC DISADVANTAGES

- Exhaust gas cleaning is an expensive process and creates particular aftercare needs for the process residues

APPLICATION DETAILS

TECHNICAL SCHEME

Significant concentrations of different harmful pollutants would be discharged to the environment with the flue gas forming during the combustion process in waste incineration facilities if no gas cleaning would be undertaken. The main purpose of exhaust gas cleaning is therefore to eliminate to the most possible extent the pollutants which can be contained in these gases as indicated in Table 2 below. Exhaust gas cleaning systems concentrate especially on the abatement of air-borne emissions and a separation of harmful components from the exhaust gas stream in such a way that certain legal standards, like the EU and other countries have fixed them, are being reliably met. These systems are therefore an obligatory and directly integrated part of incineration facilities for waste as shown below in Figure 1.

Effective gas cleaning is no uniform procedure. All processes and techniques described hereunder can be employed in a wide variety of combinations. This is making it possible to set up a process chain for the gas cleaning adapted to the different kinds of incineration input, the combustion throughput and technology employed and the specific location of the plant.

Figure 1: Example of a waste incineration scheme with the different technical components for exhaust gas cleaning directly connected to the process

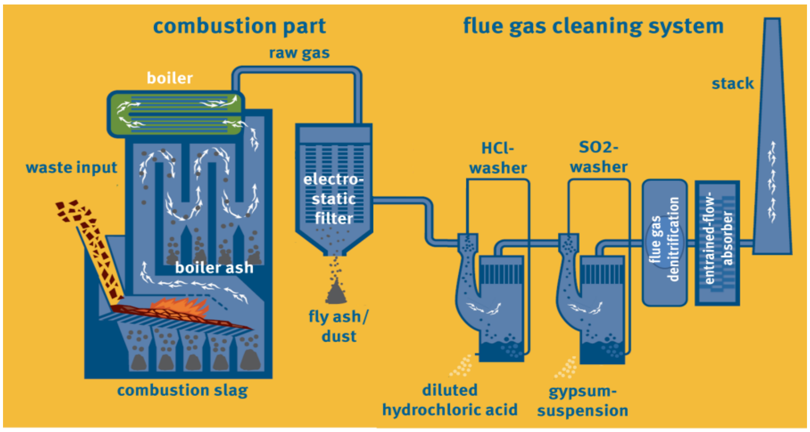

Table 2: Pollutant concentrations in the raw gas of a MSW incinerator (Source: Thomé-Kozmiensky, Löschau, 2014[1])

Polluting substances	Raw gas concentration as obtained from household waste incineration in modern facilities [mg/Nm³ dry]	
	Total range	Daily average
Total dust	800–5,000	2,500
HCl	200–2,500	1,500
HF	2–100	15
SO_2	200–1,000	600
Heavy metals	1–35	1–35
NO	Fluidized bed incineration 180–250 Grate combustion < 450	Grate combustion 350
Dioxine/Furans	1–3 ng TE	2 ng TE

[1] Immissionsschutz, Band 4. TK Verlag Neuruppin, 2014

The separation/capture of the polluting substances listed in Table 2 works as follows:

a) *Dust*

The dust contains mainly volatile heavy metals as well as a large amount of organic compounds. The content of dioxins/furans is especially large. To eliminate dust, mainly fabric filters and electrostatic precipitators are used. In single cases there are also mass force separators (such as gravity separators, cyclones or multi-cyclones) for the pre-separation of particles and wet scrubbers (venturi scrubber) in use. The following Table 3 provides an overview of the principle characteristics of these techniques.

Table 3: Principle characteristics of dust removal techniques (Source: Thomé-Kozmiensky, Löschau, 2014[1])

Separator technique	Total separation efficiency	Achievable dust content in the cleaned gas	Separable grain size x_p	Application
	%	mg/Nm³ tr.	µm	
Gravity separator	‹60	1,000	›10	Pre-separation of coarse dust
Centrifugal separator: cyclone/multicyclone	80/95	300/150	›5/›5	Pre-separation of coarse dust
Electrostatic precipitator - dry	80–99.9	25	›1	Dust extraction
Electrostatic precipitator - wet	90–99.9	‹5	›0.05	Aerosol removal
Dry separation filter fabric filter	›99.9	‹2	›0.1	Dust extraction
Wet scrubber venturi scrubber	›99.9	‹5	›0.05	Aerosol removal

b) *Acid noxious gases HCl, SO_2, HF*

Acid noxious gases can be eliminated from the exhaust gas by means of dry, semi-dry, or wet techniques. The cleaning residues from wet techniques accumulate in a diluted or suspended form (diluted hydrochloric acid, gypsum suspension) whereas in the dry and semi-dry systems they are collected in a dry solid state (e.g. natrium chloride). A dry system is characterized by spraying for example lime or sodium bicarbonate into the flue gas stream, which is passing through a quench before. The polluted matter will be eliminated by a fabric filter.

To the semi-dry systems belong the spay absorption with hydrated lime and the conditioned dry gas cleaning process with sodium bicarbonate or hydrated lime in a powdered form. The following Table 4 provides an overview on key parameters of the different systems.

Table 4: Cleaning concepts for acid noxious gases in an overview (Source: Thomé-Kozmiensky, Löschau, 2014[1])

Parameter	Wet scrubbing		Spray absorption	Conditioned dry cleaning process	Dry cleaning process	
Adsorbents	H_2O CA(OH) or $CaCO_3$	H2O NaOH	$Ca(OH)_2$	$Ca(OH)_2$	$Ca(OH)_2$	$NaHCO_3$
Physical state of the adsorbents	liquid (suspension)	liquid (solution)	liquid (suspension)	solid (powder)	solid (powder)	
Temperatur of the gas in the reactor	saturation temperature (approx. 50–60 °C)		coal: ~70°C biomass: ~100°C waste: ~140°C	coal: ~70°C biomass: ~100°C waste: ~140°C	boiler outlet temperature	
Introduction of the adsorbents	spraying		spraying	additional spraying of water	none	
Main reaction products	HCl $CaSO_4$	HCl Na_2SO_4	CaCl, $CaSO_4$, $CaSO_3$	CaCl, $CaSO_4$, $CaSO_3$	CaCl, $CaSO_4$ $CaSO_3$	NaCl Na_2SO_4
Physical state of reaction products	liquid (suspension/ solution)		solid (dust)	solid (dust)	solid (dust)	

c) <u>Nitrogen Oxides</u>

In case a removal of nitrogen oxides cannot be avoided by pyrotechnical measures, there exist mainly two processes for the removal of nitrogen oxides from the exhaust gas:

- SNCR process (Selective Non Catalytic Reduction) and
- SCR process (Selective Catalytic Reduction).

The *SNCR-process* reaches an elimination rate of NO_x of 50 to 60 % (in the most contemporary installations and under optimal conditions also up to 85%) by spraying a nitrogen compound (mostly urea or NH_3) through a nozzle into the hot flue gas (at around 850–1100°C, preferably at 950°C). It takes approx. 1 kg of ammonia to eliminate 1 kg of nitrogen oxide from the exhaust gas.

In the *SCR-process* or Selective Catalytic Reduction the flue gases are dusted off and freed from acid noxious gases first. Then nitrogen oxides are destroyed catalytically at 180 to 450°C, with the optimal range for the temperature being between 350 °C and 400°C. The same catalytic agents can be used to destroy dioxins too, if their contact surface is sufficient. The elimination rate of NO_x can go above the average of 90–92%. The demand of ammonia needed for the reduction at the catalytic converter theoretically amounts to 0.388 kg per 1 kg of nitrogen oxide eliminated from the exhaust gas.

Neither the SCR nor the SNCR generates residues, however a loss of ammonia must be observed and measures undertaken to keep this loss below the legally prescribed limits (in Germany currently prescribed in the 17. BImSchV). Both processes are summarized in the following Table 5.

Table 5: Characteristics of the two principal processes for the elimination of nitrogen oxides from exhaust gas

	SNCR	SCR
Concentration of NO_x in the cleaned gas	‹ 150 mg/m³	‹ 80 mg/m³
Advantages	- reasonably expensive - good cleaning efficiency - reduces the De-Novo-Synthesis and therewith formation of Dioxins/Furans	- very high cleaning efficiency - can be used to destroy Dioxins and Furans directly
Disadvantages	- the temperature window when the reduction agent must be sprayed into the gas stream can be easily missed in boilers with a fluctuating temperature distribution - the SNCR-process might not be effective enough to reach the prescribed values for the cleaned gas in cases where the original NO_x-rates in the raw gas are extremely high	- high costs for the maintenance of the catalytic converter - regular control and maintenance work becomes necessary due to the load of (non-removed) dust, this lowers the effective operating hours and thus the throughput - prone to react with gas components (e.g. heavy metal components) with the effect that the catalytic converter can be „poisened“ and suffer in its functionalitiy

d) <u>Heavy metals and Dioxins</u>

Dioxins, furans, and heavy metals that pass through the scrubber can be eliminated from the exhaust gas by activated carbon, activated coke, or activated carbon-lime-mixtures. Two processes are available:

- fly-flow adsorption (adding activated coke–lime and mixing it with the flue gas) and
- fixed bed adsorption (rarely in use, because of high costs and vulnerability to failures)

Heavy metals (especially mercury and cadmium) as well as dioxins/furans that pass through scrubber systems can be eliminated from the exhaust gas with the help of activated carbon/hydrated lime suspension. Very reliable as a cleaning process has proved fly-flow adsorption working on the basis of a coke or lime/sodium bicarbonate mixture brought in contact with the exhaust gas. Fixed bed adsorption is rarely used mainly due to the higher costs and more difficult handling of the process. The main features of both processes are summarized in Table 6 below.

Table 6: Processes used for an adsorption of heavy metals and dioxins/furans during exhaust gas cleaning

	Fly-flow adsorption	Fixed bed adsorption
Concentrations in the cleaned gas: - Dioxins - Heavy metal	<< 0,1 ng TE < 0,1 mg	<< 0,1 ng TE < 0,1 mg
Temperature	max. 150 °C	max. 150 °C
Advantages	- good cleaning efficiency - reasonably expensive	- very high cleaning efficiency - non-sensitive to a variation of the gas concentrations
Disadvantages	- Risk of slip-through (under high loads)	- Risk of fire - expensive - high CO-emissionen during start-up operations
Adsorbents and residues of them	activated carbon or coke partly in a mix with lime and/or sodium bicarbonate	activated carbon or coke

Activated carbon or coke bind heavy metals (primarily mercury and cadmium) as well as dioxins/furans. Next to this, a slight up-concentration of sulfur and chorine can be achieved. As a rule, these materials are returned to the boiler, as long as Hg and Cd are precipitated in flue gas precipitation (e.g. an acidic scrubber).

QUANTITY ASPECTS

The possible reduction rates for the different pollutants in the exhaust gas are described above in conjunction with the different cleaning techniques employed

SCALE OF APPLICATION

- A cleaning of the exhaust gases from combustion processes has to be an integrated part to all kinds of waste incineration facilities according to legal requirements. See therefore also the fact sheets on the different incineration technologies; "Industrial Co-combustion", "Grate combustion", "Fluidized bed incineration"

INTEROPERABILITY

- Techniques that provide for a cleaning of the exhaust gases can be integrated to any combustion system, including thermal facilities not using waste as an input material

OPERATIONAL BENCHMARKS: RESOURCE CONSUMPTION

ENERGY BALANCE

CO_2-BALANCE

- both determined by the applied combustion process and the intensity of the emissions resulting from it

AIDS/ADDITIVES NEEDED

- sodium bicarbonate, limestone/powdered limestone or lime hydrate (slaked lime) to absorb respectively reduce acid pollutant gases
- Coal, coke from lignite for the absorption of heavy metals and dioxins: <0.8 kg/Mg waste input
- Urea or ammonia water (25%) for NO_x-reduction)
- Water

HUMAN RESOURCES

- The gas cleaning process does not rise the personnel demand in addition to the staffing requirements of the incineration facility where it is operated, however there is an additional disposal need for the residues from exhaust gas cleaning which must be attended and causes personnel to work on

SPATIAL NEEDS

- The additional space demand for boiler installations including the appropriate exhaust gas cleaning systems is substantial when compared with the system proper for the ordinary combustion. When dimensioning the area some reserve space should be considered for upcoming measures to retrofit or upgrade the gas cleaning system.

OPERATIONAL BENCHMARKS: COST DIMENSIONS

INVESTMENT COSTS

Dry and quasi-dry exhaust gas cleaning systems are marked by the lowest capital requirements in comparison to other options. Wet sorption processes show a larger range in their necessary investment costs. However, the investment needs for a simple wet sorption system may only slightly rise above that for a quasi-dry exhaust gas cleaning system.

Capital investment per unit to be set up (average price range established in 2008):

Example: Incineration throughput at 200,000 Mg/a; simple exhaust gas cleaning (dry)

- Construction costs : 4,500,000 EUR
- Equipment : 13,000,000 EUR
- Additional expenses, financing: 3,500,000 EUR

Example: Incineration throughput at 200,000 Mg/a; more complex gas cleaning system (wet)

- Construction costs : 7,500,000 EUR
- Equipment : 20,000,000 EUR
- Additional expenses, financing: 5,500,000 EUR

The total system investment (capital expenses) taking a dry sorption exhaust gas cleaning in different configurations as an example can be in the range from EUR 8 million (with SNCR) to EUR 12 million.

The investment required to set up a SCR or SNCR system of different efficiency can differentiate as follows:

Table 7: Investment costs for SCR and SNCR gas cleaning processes (Source: Beckmann, 2011[2])

SNCR process	NO_x-cleaned gas concentration	mg/Nm³ dry	200	150	100
	Total investment	EUR	265,000	280,000	525,000
SCR process	NO_x-cleaned gas concentration	mg/Nm³ dry	150	100	50
	Total investment	EUR	2,280,000	2,308,000	2,365,000

OPERATING COSTS

- The running costs strongly depend on the market prices for cleaning agents and auxiliary materials. The following Table 8 displays some orientation values for operating materials despite of the fact that prices for them often fluctuate on the market

Table 8: Cost examples for operating materials in gas cleaning processes (Source: Beckmann, 2011[2])

Material	Price
Sodium bicarbonate (98 mass-% $NaHCO_3$)	230 EUR/Mg
Activated coke	420 EUR/Mg
Ammonia water (25 mass-% NH_3)	100 EUR/Mg
Dilution water (Deionat)	4 EUR/Mg
Disposal costs for gas cleaning residues	135 EUR/Mg

- Repair and maintenance costs: for each structural element approx. 1% of the initial investment; for machinery and electronic parts: approx. 3–4% of the initial investment
- The overall operating expenses taking a dry sorption exhaust gas cleaning in different configurations as an example can be in the range of approx. EUR 1.5–2.3 million per annum

POSSIBLE PROCEEDS

- From the sale of FGD gypsum and hydrochloric acid (in a cleaned state) which are both by-products from exhaust gas cleaning

MASS SPECIFIC OVERALL COSTS

- are included in the figures provided for the different waste incineration technologies; see therefore also the fact sheets on “Industrial Co-combustion“, “Grate combustion“, and “Fluidized bed incineration“

[2] Beckmann: Beschreibung unterschiedlicher Techniken und deren Entwicklungspotentiale zur Minderung von Stickstoffoxiden im Abgas von Abfallverbrennungsanlagen, Umweltbundesamt 2011, http://www.uba.de/uba-info-medien/4196.html

OTHER RELEVANT ASPECTS

MISCELLANEOUS

MARKET INFORMATION

REFERENCE FACILITIES *(Note: the list of sites and/or firms does not constitute a complete compilation)*	- See the fact sheets on the different incineration technologies; "Industrial Co-combustion", "Grate combustion", "Fluidized bed incineration"
RECOGNIZED PRODUCER AND PROVIDER FIRMS *(Note: the list of firms does not constitute a complete compilation of companies)*	Recognized producer/provider firms for exhaust gas cleaning technology and components in Germany are for example: - LAB GmbH, Stuttgart www.labgmbh.de - MARTIN GmbH für Umwelt- und Energietechnik, München www.martingmbh.de - ENVIROTHERM GmbH, Essen www.envirotherm.de - Hitachi Zosen Inova Kraftwerkstechnik GmbH, Landsberg www.hz-inova.com - Steinmüller-Babcock Environment GmbH, Gummersbach www.steinmueller-babcock.com

ADDITIONAL REMARKS AND REFERENCE DOCUMENTS

Further information and compilations on relevant details and plants can be obtained from:

- ITAD – Interessengemeinschaft der thermischen Abfallbehandlungsanlagen in Deutschland e.V. www.itad.de
- CEWEP – Confederation of European Waste-to-Energy Plants www.cewep.com